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NONDESTRUCTIVE TESTING FOR FIELD WELDS: REAL TIME WELD QUALITY --ETC(U)
JUN 81 F KEARNEY, R WEBER, P WILLIAMS

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June 1981
NDT Weld Quality Monitor/Semi-Automatic Welding

NONDESTRUCTIVE TESTING FOR FIELD WELDS: REAL TIME WELD QUALITY MONITOR—FIELD TESTS

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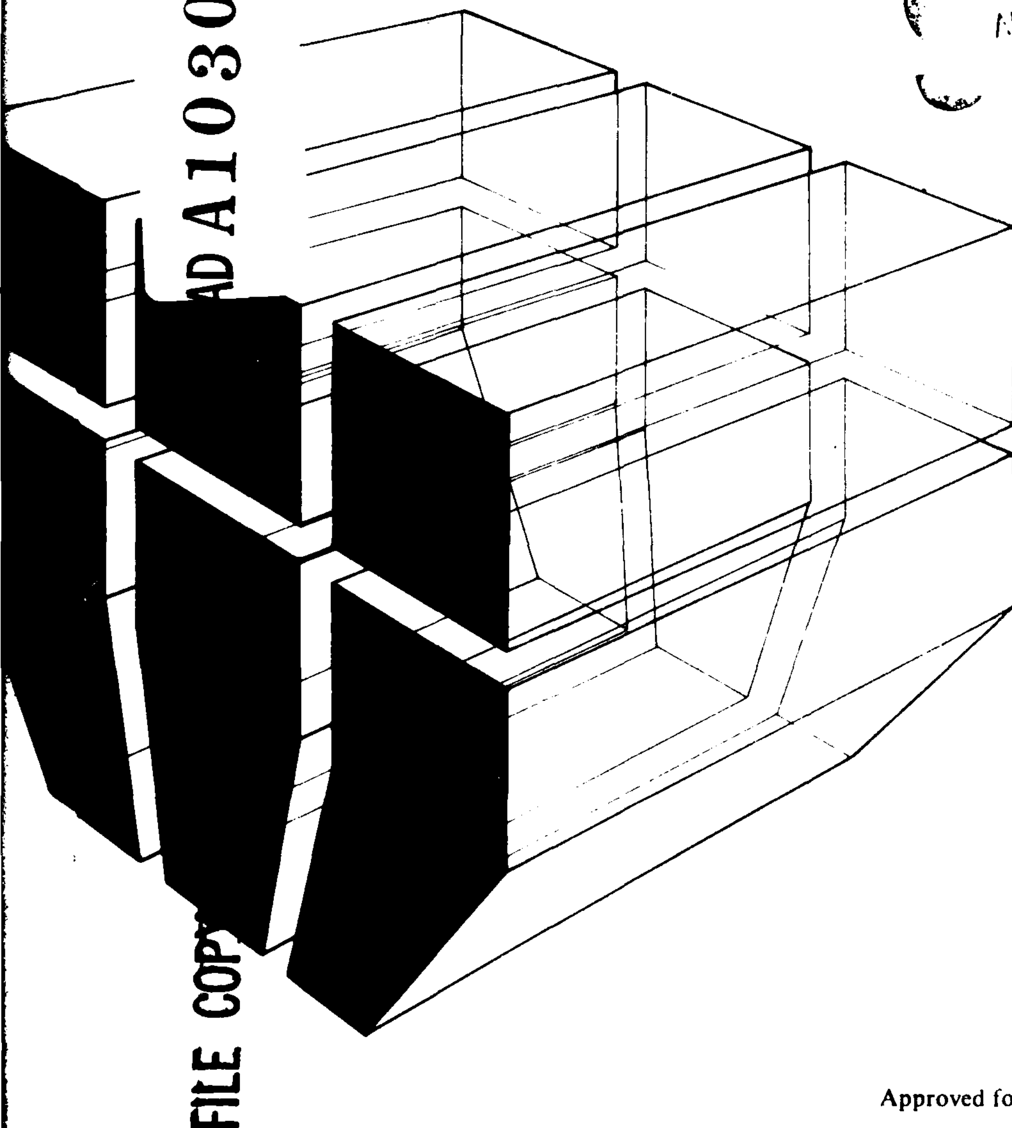

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This report documents the laboratory and field testing conducted on the weld quality monitor (WQM) developed by the U.S. Army Construction Engineering Research Laboratory. Results of the laboratory testing showed that all channels of the weld monitor performed satisfactorily, both independently and in conjunction with each other. Field testing showed a one-to-one correspondence between an anomalous event and WQM output. It has therefore been concluded that the WQM now meets the basic requirements for Army field operations.

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FOREWORD

This investigation was conducted by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Military Programs, Office of the Chief of Engineers (OCE). The research was funded under Project 4A762731AT41, "Design, Construction, and Operations and Maintenance Technology for Military Facilities"; Task A, "Construction Systems Technology"; Work Unit 041, "NDT Weld Quality Monitor/Semi-Automatic Welding." The QCR is 3.07.003. Mr. E. Hunt (DAEN-MPC-E) is the OCE Technical Monitor.

Dr. R. Quattrone is Chief of EM. COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

NONDESTRUCTIVE TESTING FOR FIELD WELDS: REAL TIME WELD QUALITY MONITOR—FIELD TESTS

1 INTRODUCTION

Background

During the welding process, changes in arc voltage, travel speed, and heat input can occur without the operator's knowledge. These changes can cause defects such as porosity, slag inclusions, incomplete fusion, and undercut in the deposited weld metal (Appendix A). The cost of locating and repairing these defects can be a major portion of Army construction costs; welding inspection can constitute 25 to 40 percent of the weld fabrication cost. In addition, weld defects decrease the service life of welded joints. Consequently, it is necessary to monitor the welding parameters to detect, identify, and locate possible defects. A weld monitor with real time output would help the inspector designate suspect areas for nondestructive testing. In addition, by operating in real time, the weld monitor could be used to interrupt welding or to produce corrective signals for the welding power supply at the incipient stage of defect occurrence, thus preventing costly rework.

The need for this type of system is increasing as the Corps of Engineers becomes more involved in projects requiring welding construction, as in the MX Missile programs. To address this need, the U.S. Army Construction Engineering Research Laboratory (CERL) is conducting research to develop a field portable weld quality monitor (WQM). Essentially, the WQM is intended to provide a mechanism to merge the welding engineer's design intent with the actual field welding process.

In the initial phase of study,[1] several requirements were established for the device. It should:

1. Monitor the three primary signals from the weld system: arc voltage, current, and travel speed; compare them to preset limits; and alert the operator if the limits are exceeded.

2. Calculate the heat input, nugget area, and cooling rate from the three primary signals; compare these values with preset limits; and alert the operator if these limits are exceeded.

3. Be field portable.

4. Interface easily with in-situ welding equipment.

Following development of these requirements, a prototype WQM was designed, fabricated, and tested, using input from a fully automated gas metal-arc (GMA) welding machine.[2] The automated GMA process was chosen to obtain close control and reproducibility of the welding variables during initial testing.

Appendix B describes the WQM circuitry.

Objective

This study is being conducted in several phases. The first phase established requirements for and developed a prototype WQM device. A field test of this laboratory prototype WQM was conducted to evaluate its performance under field conditions.[3]

The objective of this phase was to conduct laboratory and field tests to determine the adequacy and field applicability to Army construction projects of the WQM design that evolved from the previous work.

Future phases of the WQM study are intended to develop (1) suitable speed sensing systems for manual welding situations, (2) specific radiometric measurement techniques involving acoustic and opto-electronics spectral analysis, and (3) digital processing features using microprocessors to facilitate the programming of the WQM.

Opto-electronic weld evaluation techniques (see Appendix C) now being developed will be used in further WQM development to provide a more powerful configuration.

Approach

The design of the prototype WQM developed in the initial study was modified to incorporate improvements indicated during actual laboratory welding situations, improvements suggested during consultations with Government and private-sector personnel, and the results of the prior field testing. Hardware was assembled and packaged for field use.

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[1] R. Weber, F. Kearney, and S. Joshi, *Development of Weld Quality Monitor*, Interim Report M-183 ADA027644 (U.S. Army Construction Engineering Research Laboratory [CERL], July 1976).

[2] Weber, et al., *Development of Weld Quality Monitor*.

[3] F. Kearney, *Nondestructive Testing for Field Welds: Real Time Weld Quality Monitor*, Interim Report M-251 ADA058129 (CERL, August 1978).

The unit was then installed in a welding situation that would thoroughly test all modes of its operation.

Mode of Technology Transfer

The results of this study will impact TM 5-805-7, *Welding: Design Procedures and Inspection* (Department of the Army, 15 March 1968).

2 LABORATORY TEST

Procedure

Each channel of the WQM was tested individually with a variable signal similar in current and voltage level to the signal from a welding machine. The limits for each channel were set, and the test voltages were varied to simulate changes in the primary signals. When the status lights indicated that the limit had been exceeded, the test voltage was compared to the preset limit value to check the accuracy of the comparator circuit.

After each channel had been tested successfully, the three simulated primary signals were fed into the monitor simultaneously. The limits were set again and the input voltages varied. All circuits, including the analog computer section, were checked for accuracy and reproducibility.

The monitor was then connected to the CERL welding machine to test the circuitry with actual signals. After the limits were set, a welding arc was established on a test plate.

Results

Results of the laboratory testing showed that all channels performed satisfactorily, both independently and in conjunction with each other. The warning lights were triggered when the input signal exceeded the limits set by the reference signal, and no difficulties were encountered when the limit span was changed.

While investigating the signals of the three parameters (voltage, current, and speed), it was found that the voltage and amperage signals contained spurious noise signals. These signals were removed by (1) incorporating filters in the data channel to eliminate the peaks and smooth out the signals, thus reducing the chance of damage to components, and (2) replacing the shunt used for the amperage signal source with a Hall effect solid state transductor. (The advantage of using the transductor is that it is not directly connected to the welding cable as the shunt is; instead, it fits around the cable and measures the magnetic field generated by the current passing through the cable.) The transductor minimized amperage transient signal problems; filters were installed in all channels for field contingencies.

The modifications indicated by the laboratory testing program were incorporated into the monitor before field testing. Figure 1 shows the system assembled for field testing.

3 FIELD TEST

Site Selection

The two general types of welding operations considered for field testing were (1) shop fabrication, which uses automated welding equipment, and (2) field fabrication/repair, which generally involves manual or semi-automatic welding and is more dependent on the operator's subjective judgment.

In addition, it was decided that field tests would be more conclusive if the weld quality monitor were used in conjunction with some other form of nondestructive testing. Three sites were available that offered these combinations: (1) Flint Steel Corporation, Tulsa, OK; (2) a hydroelectric turbine shaft repair job at Ozark Powerhouse, Ozark, AK;[4] and (3) new construction of a wind tunnel facility at USAF Arnold Engineering Development Center, Tullahoma, TN. The Tullahoma, TN, construction the largest welding project ever undertaken by the Corps of Engineers—was chosen. Researchers felt that the time and space constraints of this field erection situation would assess the unit's adaptability most rigorously. In addition to the hardware evaluation, the field test would provide an opportunity for welding personnel from the private sector to appraise the WQM.

Test Operations

Transporting the WQM and auxiliary equipment from CERL to the Arnold Engineering Research and Development Center (AERDC) for testing required no special handling. The equipment was set up by maintenance personnel and was ready for operation in less than 2 hours. The WQM was set up approximately 25 ft (7.5 m) from the welding station. Figure 2 shows the configuration of the welding station. Figure 3 shows the unit connected for testing.

[4] F. Kearney, *Nondestructive Testing for Field Welds: Real Time Weld Quality Monitor*, Interim Report M-251 ADA058129 (CERL, August 1978).

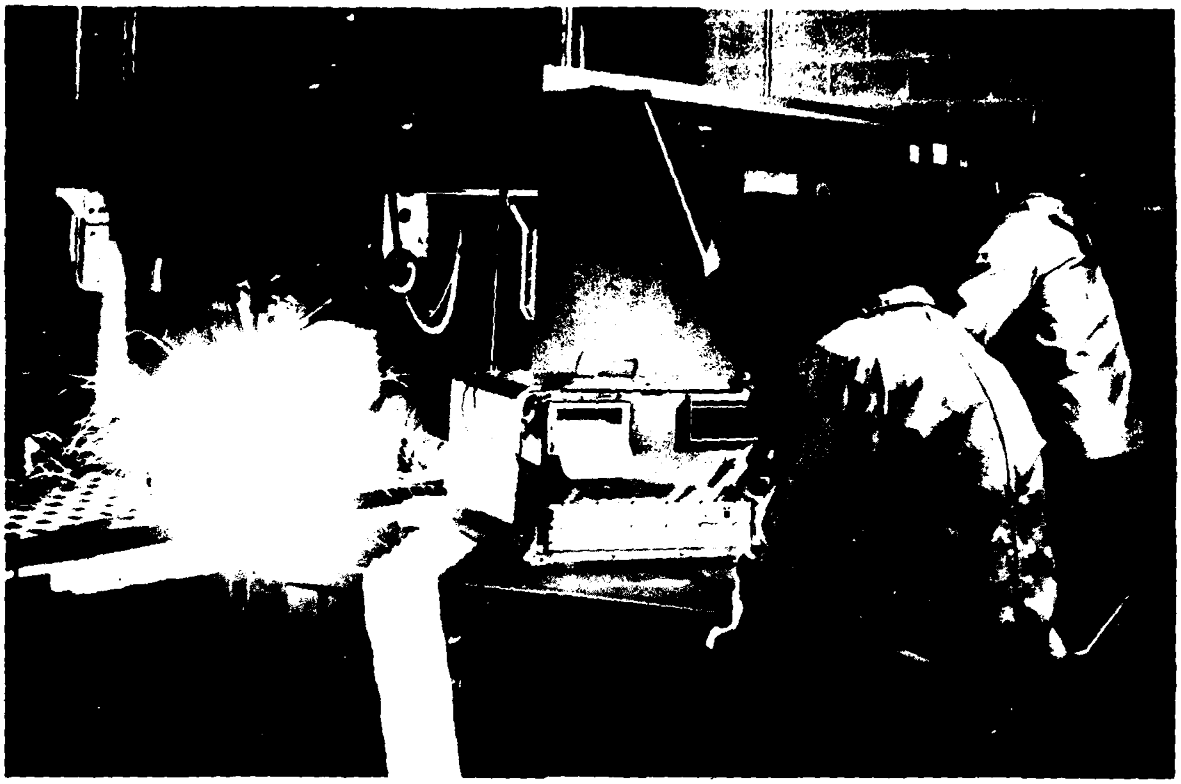


Figure 1. Field-tested weld quality monitor prototype.

Figure 2. Field welding station showing submerged arc welding unit and windbreak.

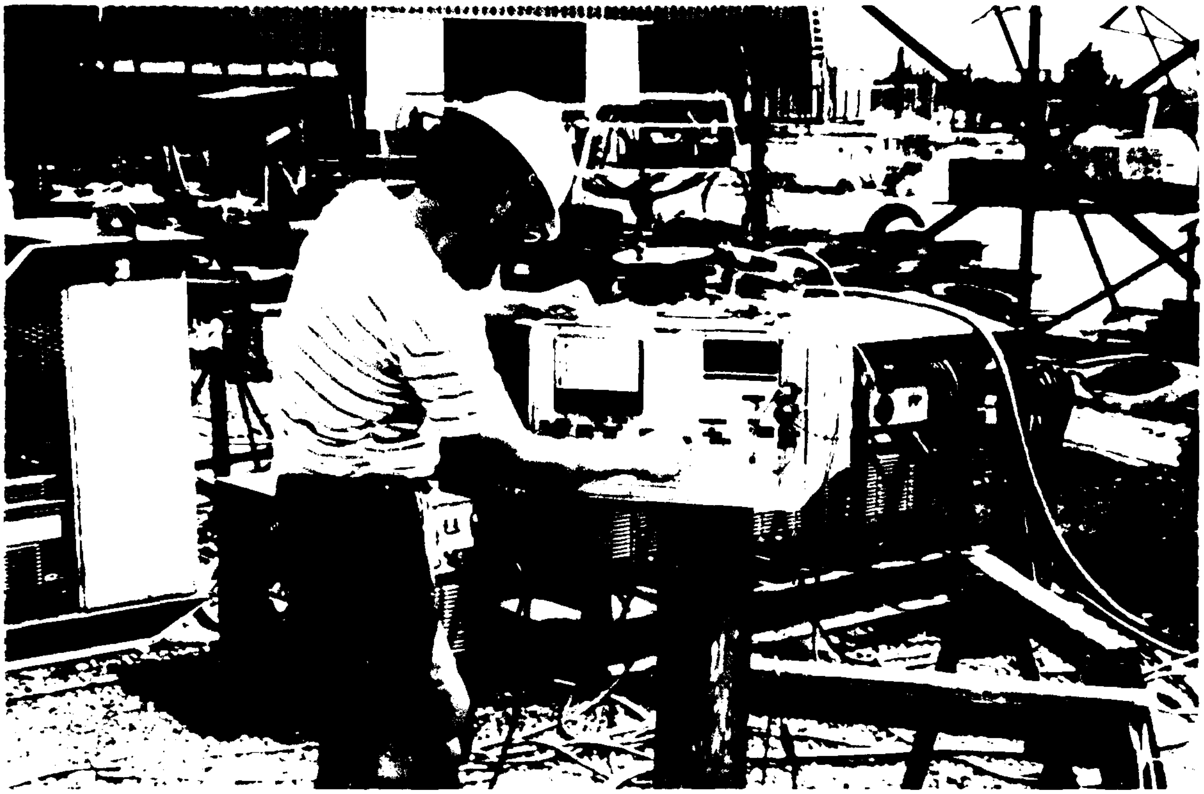


Figure 3. Weld quality monitor connected for testing.

Figure 4. Installation of the Hall effect device on welding cable.

Installation of the Hall effect current transductor (see Figure 4) involved simple disconnection and reconnection of one of the leads from the welder power unit; no hard wiring was required.

The voltage sensors were attached to the welding power supply because of the inaccessibility of the slip ring arrangement on the welding head.

The WQM was attached to a submerged arc welding system that connected flange to pipe for penetrations in the test cell. The circular operation of the welding head did not allow for the travel speed to be tested, because no slip ring was available for transmitting the voltages. Therefore, a precision voltage source was used to provide an equivalent speed signal to compute heat input and nugget area. For this mode of operation, a voltage corresponding to a particular welding speed was input to the analog computer module to compute heat input and nugget area (Equations A1 and A3, Appendix A). For example, if the analog module were scaled for 1 volt = 1 in. min, then a 6-volt signal from the precision voltage source would be input for a welding speed of 6 in. min.

Figure 5 shows a typical voltage and current time trace obtained from the WQM. These signals were taken at the output of the signal conditioners before filtering for inputting to the comparators. As shown in Figure 5, the signal is not distorted, and shows the response of the sensors to the voltage and current variations that occur in the arc. Because the parameter data content is preserved in the transduction and conditioning process, the data can be used in several ways from simple alarms to adaptive control systems.

The unit used in this test incorporated an "event" recorder output device, which provided a "blip" mark on a time baseline to indicate which parameter deviated from the preset limits. It also indicated the direction of error, i.e., high or low excursion. Figure 6 shows a representative trace obtained during the field test.

Results of Operational Testing

Since the accuracy of the parameter measurement systems and the computational sections was verified in the laboratory, the primary field test criteria were the unit's response and correlation to deviant conditions. The welding operations were visually observed by CERL personnel for each flaw-inducing occurrence, and the event recorder was appropriately annotated at each incident (see Figure 6). The flaw-inducing conditions that occurred were typical of field welds. Three hundred feet of data tape were obtained in the test, with 700 "out of limit" events recorded. Subsequent analysis of the event recorder traces showed a one-to-one correspondence between an anomalous event and the WQM output. Furthermore, the cross-correlation between measured signals, voltage, current, and speed and computed parameters (heat input and nugget area) showed good agreement; e.g., a deviant current value indicated an error in the heat input and nugget area channels.

The correlation of WQM output with flaw-inducing welding events, as determined by this test, indicates that the basic requirements for an Army-fieldable unit have been demonstrated.

4 CONCLUSION

Based on the laboratory and field tests, the WQM design is adequate and has field applicability.

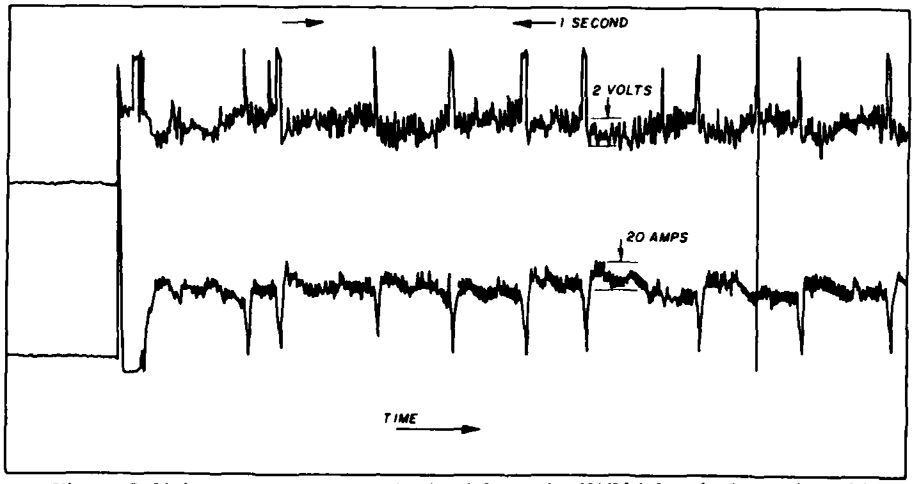


Figure 5. Voltage current trace obtained from the WQM for shaft repair weld.

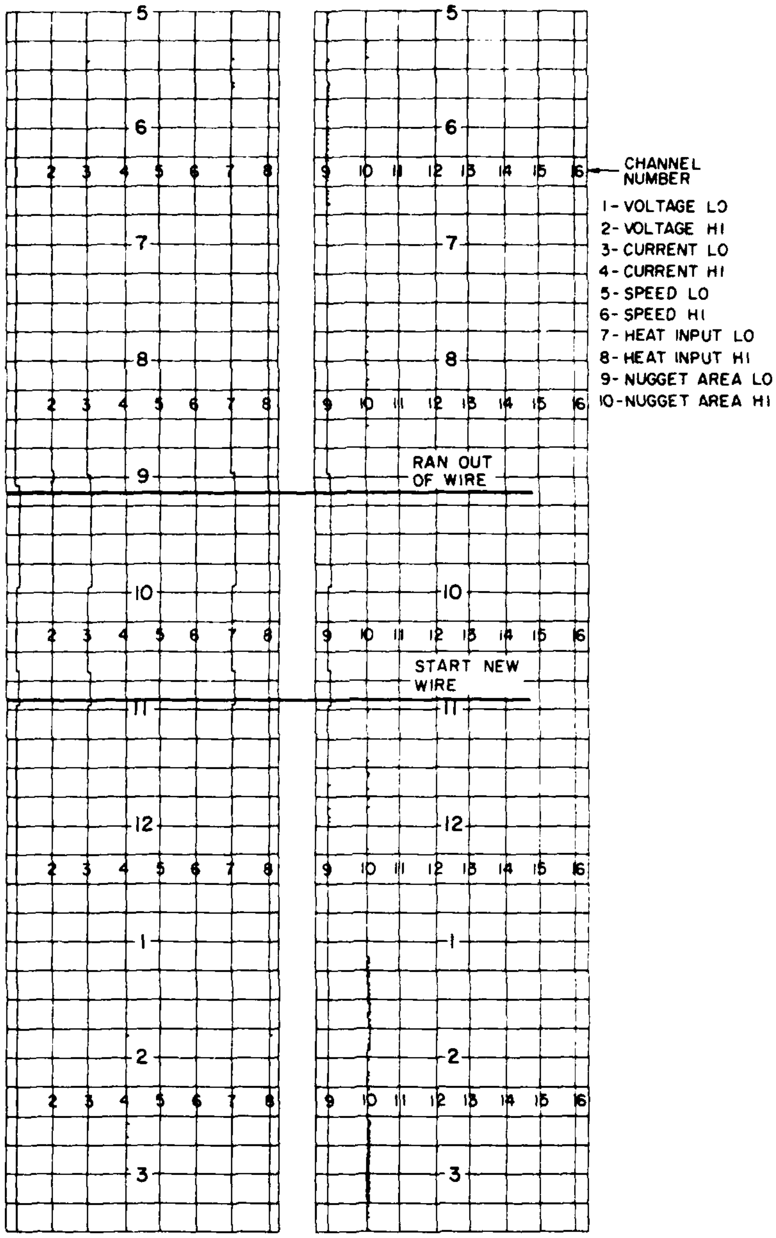


Figure 6. Typical trace from the event recorder of the weld quality monitor.

APPENDIX A: FACTORS AFFECTING WELD METAL MECHANICAL PROPERTIES

Defects

Changes in arc voltage, travel speed, and heat input during welding can cause several types of defects in the deposited weld metal.

Porosity is a void or gas pocket trapped in solidifying weld metal. The reduced solubility of the gas in the metal caused by the decreasing temperature forces the gases out of solution. The gases are originally introduced either by poor shielding, which entrains air, or by chemical reactions in the molten weld metal. Stick electrodes with too long an arc as a result of excessive arc voltage can reduce shielding effectiveness and introduce gas into the metal.

Slag inclusion is the entrapment of an oxide or other nonmetallic material under the weld bead. The major source of slag is the coatings on stick electrodes. This defect is related to heat input.

Incomplete fusion is the failure of adjacent layers of the weld metal or weld base plate to fuse. Incomplete fusion may result when the adjacent metal is not heated to the melting point because of insufficient heat input.

An **undercut** is a groove melted into the baseplate at the toe of the weld and is caused primarily when **travel speed** is excessive in relation to the welding current.

In addition to the defects caused by improper control, the heat generated by the welding process can change the base metal in the following ways:

1. Grain coarsening

2. Softening (annealing effects)

3. Hardening (phase precipitation or transformation)

4. Segregation of constituents

5. Grain boundary melting

6. Loss of ductility

7. Loss of toughness

8. Residual stresses causing distortion or cracking.

The type of change depends on the chemical composition of the base metal, the electrode, and the heat history of the base plate.

In the two commonly used field welding processes —shielded metal-arc (stick electrodes) and gas metal-arc (bare-wire)—the source of heat for melting the materials is an electric arc. Control of the arc parameters will control the amount of heat generated, the length of time the weld metal is at an elevated temperature, and the cooling rate of the weld zone.

Base Metal Microstructure

The cooling cycle after a weld pass determines the microstructure of the weld metal and the heat-affected zone. With fast cooling rates, some steels become very hard because of a martensitic transformation. If the cooling rate is sufficiently slow, the metal may be more ductile and the structure ferritic and pearlitic. The type of steel generally determines which of these structures is most desirable. For low-carbon and low-alloy steels, the pearlitic structure is desirable, while for high-strength quenched and tempered steel, the martensitic structure is desirable.

Martensite is undesirable in low-carbon and low-alloy steels designed for yield strengths of less than 80 ksi (552 MN/m^2) because of its hardness and low solubility for hydrogen at ambient temperatures. This combination of characteristics increases the likelihood of hydrogen cracking in the joint. Use of low-hydrogen stick electrodes and the gas metal-arc welding system reduces this tendency toward hydrogen-induced cracking.

Cooling Rate Control

Controlling the cooling rate is essential to prevent undesirable microstructure in the weld and heat-affected base plate. A mathematical combination of arc voltage, current, and travel speed known as heat input (HI) has been used to control cooling rate for many years. The equation for calculating heat input is

$$\text{HI (J/in.)} = \frac{\text{voltage} \times \text{amperage} \times 60}{\text{travel speed (in./min.)}} \quad \text{[Eq A1]}$$

The normal maximum has been 55,000 to 60,000 J/in. (21 654 to 23 622 J/cm) for the field processes mentioned above. Another means of controlling cooling rate has been preheat treatment. Dorschu[5]

[5] K. E. Dorschu, "Control of Cooling Rates in Steel Weld Metal," *Welding Research Supplement* (February 1968).

has shown that the relationship between heat input, preheat temperature, and cooling rate is:

$$CR = \frac{m(T - T_o)^2}{HI} + c \qquad \text{[Eq A2]}$$

where CR = cooling rate
T = test temperature, 1000°F (538°C)
T_o = preheat temperature
m,c = constants
HI = heat input (kJ/in.)

Eq A2 indicates that the higher the preheat temperature and heat input, the slower the cooling rate.

Shultz and Jackson[6] have shown that the cross-sectional area of the weld bead is a useful indicator of weld metal mechanical properties and that a relationship exists between the area and cooling rate. They also found that arc voltage has little or no effect on the nugget area and cooling rate. The relationship that Shultz and Jackson have developed for nugget area, arc current, and speed is:

$$na = 122 \times 10^{-7} \frac{i^{1.55}}{S^{.0903}} \qquad \text{[Eq A3]}$$

where na = nugget area (sq in.)
i = arc amperage
S = arc travel speed (in./min).

[6] B. L. Shultz and C. E. Jackson, "Influence of Weld Bead Area on Weld Metal Mechanical Properties," *Welding Research Supplement* (January 1973).

APPENDIX B: CIRCUIT DESCRIPTION

Figure B1, a block diagram of the weld quality monitor, shows the input signals from the welding arc. These signals are conditioned to standard values and sent to the comparator module, which compares the input signals with a set of limit signals.[7] If the input signals are too high or too low, the appropriate alarm is triggered. The input signals are also transmitted to the analog computer module for calculating of the heat input, cooling rate, and nugget area. The calculated values are then compared to reference signals, and the appropriate alarm is triggered if needed.

[7] R. A. Weber and C. E. Jackson, *Review of Weldability of Construction Materials*, Interim Report M-168 ADA027383 (CERL, January 1976).

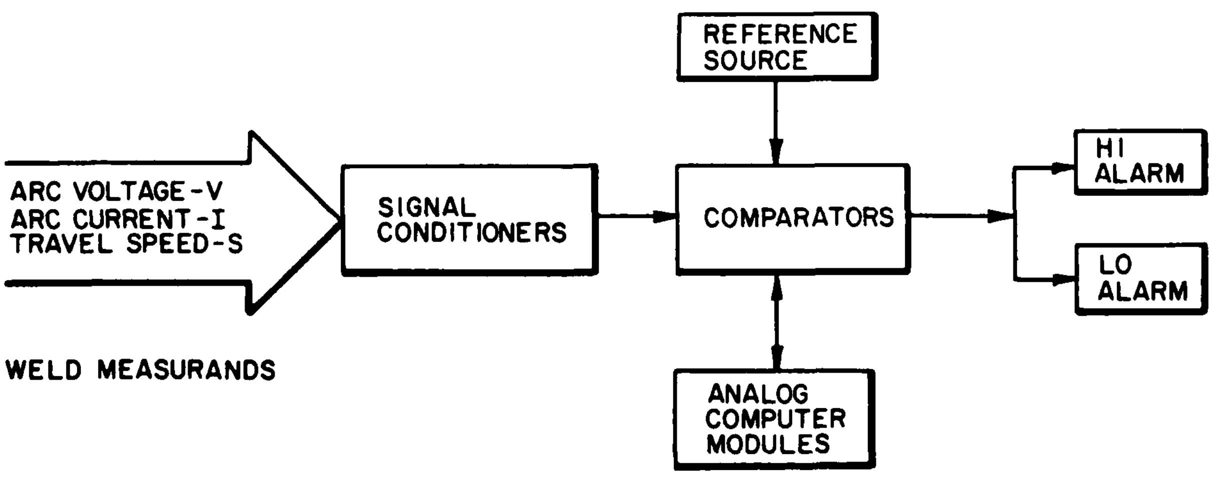


Figure B1. Block diagram of weld quality monitor, showing input signals from the welding arc.

APPENDIX C: OPTO-ELECTRONIC WELD EVALUATION (OWE)

Direct quantitative measurements of certain parameters of welds in process are not possible for several reasons:

1. The high weld temperatures destroy sensors near the weld area.

2. Contacting sensors introduce a discontinuity into the weld process, causing data uncertainty.

3. In the case of manual welding, subjectiveness peculiar to the welder is indeterminant and variable.

Some indirect measurements such as thermocouples are used, but these techniques exhibit time lags, averaging effects, and other factors that decrease the validity and reproducibility of the information.

Because of this inability to measure directly and instantaneously the quantities relevant to a satisfactory weld, a research program was implemented to produce noncontacting instrumentation techniques. These techniques, which use opto-electronic technology, can be used in the field to directly monitor pertinent weld measurements such as cooling rate, weld speed, and heat input. The measurements can then be used as input to the CERL weld quality monitor.

Opto-electronic technology is used to detect the amplitude and wave length of radiation emitted by the welding arc. A photodetector (or an array of photodetectors), which is the primary sensor, has appropriate circuitry to provide the required output information.

Physics of the Welding Arc

The welding arc can be thought of as a gaseous conductor which changes electrical energy into heat. The welding arc can be defined as a particular group of electrical discharges that are formed and sustained by the development of a gaseous conductive medium. The current carriers for the gaseous medium are produced thermally and by field emission.

The arc current is carried by the *plasma*, the ionized state of a gas composed of nearly equal numbers of electrons and ions. Mixed with the plasma are other states of matter, including molten metals, slags, vapors, neutral and excited gaseous atoms, and molecules. Measured values of welding arc temperatures normally range between 5000 and 30,000° K, depending on the nature of the plasma and the current conducted by it.

The amount and character of spectral radiation emitted by arcs depend fundamentally on the atomic mass and chemical structure of the gas, the temperature, and the pressure. Spectral analysis of arc radiation shows bands, lines, and continua. Analysis of radiation from organic-type covered electrodes shows molecular bands caused by the existence of vibrational and rotational states, as well as line and continuum emissions from excited and ionized states. The inert gas arcs radiate predominantly by atomic excitation and ionization. As the energy input to arcs increases, higher states of ionization occur, which causes radiation to be emanated from higher energy levels.

In this study, the fundamental method used to develop noncontacting sensors was separation and quantification of segments of weld spectra that could be correlated to specific weld parameters. Figure C1 shows the visible spectrum and a portion of the infrared spectrum emanating from the argon-shielded gas tungsten arc.

Optical Electronic Transduction Methods

Two methods of segmenting or partitioning weld spectra are (1) selection of photosensors having a spectral response only in the sections of the spectrum to be measured, and (2) use of optical filters to limit the wave length of radiation impinging on the photodetector. For this work, the latter method was used. Figure C2 illustrates the radiation physics and adaptation of optical electronics in the application to welds. Various combinations of commercial photographic filters made it possible to segment the arc spectra into about five bands; this provided adequate resolution to quantify weld flaws, as well as being an extremely flexible procedure. Two examples will briefly illustrate this process.

An analysis of the metallurgical phase diagrams associated with weld nugget area suggested that the normal (acceptable) weld spectrum and a deviant spectrum characterizing a flaw would have wave lengths greater than 700 nanometers. To implement the "front end" of the sensor system, a Wratten-type 89b filter was selected and coupled with a type TIL-63 phototransistor. This provided a sensor system with a photometric "window" of about 700 to 1050 nanometers; thus, the desired spectra were detected while extraneous spectra were attenuated.

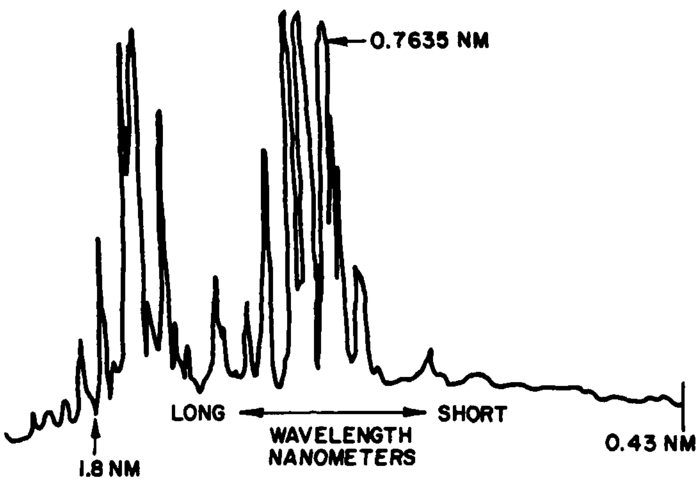


Figure C1. Spectrum of the argon-shielded gas tungsten arc.

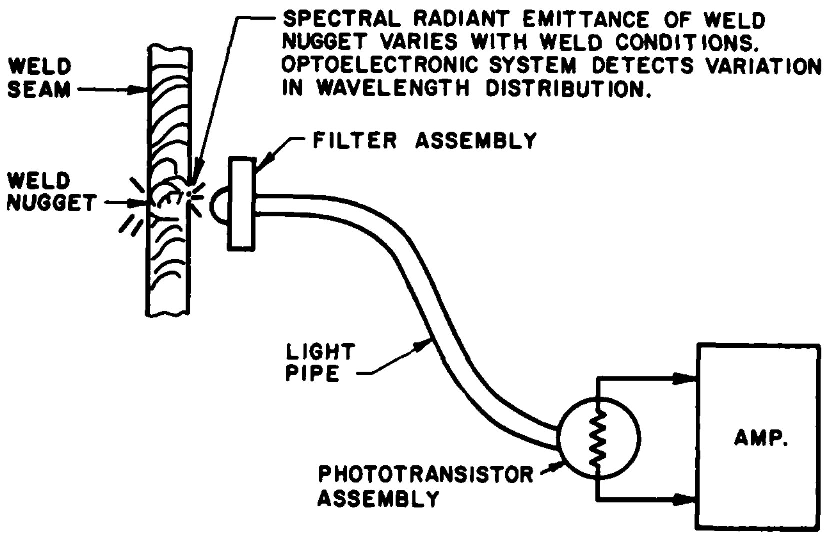


Figure C2. Opto-electronic system and application to welds.

A fiber optic light pipe was the transmission device between the arc and the phototransistor. Weld arc instability or "sputtering" is one of the most common flaw-inducing conditions encountered in the field. Laboratory testing with radiometers indicated that spectral lines emitted by an unstable arc were very dense in the visible range; a ratton 57 cylinder placed in the front end to quantify this phenomenon showed notable results. Another flaw-inducing condition detected by this device was magnetic arc blow.

Current opto-electronics research is concentrated on developing rugged, high-temperature optical systems that will be durable enough for field use. The results are very encouraging; the fiber optic bundles used in these devices are 1 16 to 1 8 in. (1.6 to 3.2 mm) in diameter and have a pass band in the required range of .4 to 1.9 nm.

Large Scale Integration (LSI) and the WQM

The primary factor that makes the WQM a practical tool is the confluence of welding engineering and large-scale integration electronics technology. Measurements and recordings of voltage, current, and more recently, acoustic emission data are becoming quite standard. The CERL WQM is innovative and unique in that it uses this data for *in-situ, real-time* analysis for *continuous* and *instantaneous* quality assurance.

OWE Status 1980

In CERL's prototype opto-electronic system configured for field use, the spectrum is segmented and quantified by a grooved spectrograph and linear photodiode array. A high-temperature fiber optic bundle is routed along the flexible cable hose assembly to the welding gun so as not to interfere with normal welding operations. This versatility makes the system applicable to manual welding, which is the principal method used by the Army. CERL has successfully tested this configuration, and has found that it can distinctly characterize flaws caused by slag inclusions, loss of flux, loss of the argon cover gas, and magnetic arc blow. Figure C3 shows the arc spectral change for an argon gas cover system when the gas flow is interrupted.

REFERENCES

Dorschu, K. E., "Control of Cooling Rates in Steel Weld Metal," *Welding Research Supplement* (February 1968).

Hackforth, H. L., *Infrared Radiation* (McGraw-Hill Book Co., 1960).

Kearney, F., *Nondestructive Testing for Field Welds: Real Time Weld Quality Monitor*, Interim Report M-251 ADA058129 (CERL, August 1978).

Schultz, B. L., and C. E. Jackson, "Influence of Weld Bead Area on Weld Metal Mechanical Properties," *Welding Research Supplement* (January 1973).

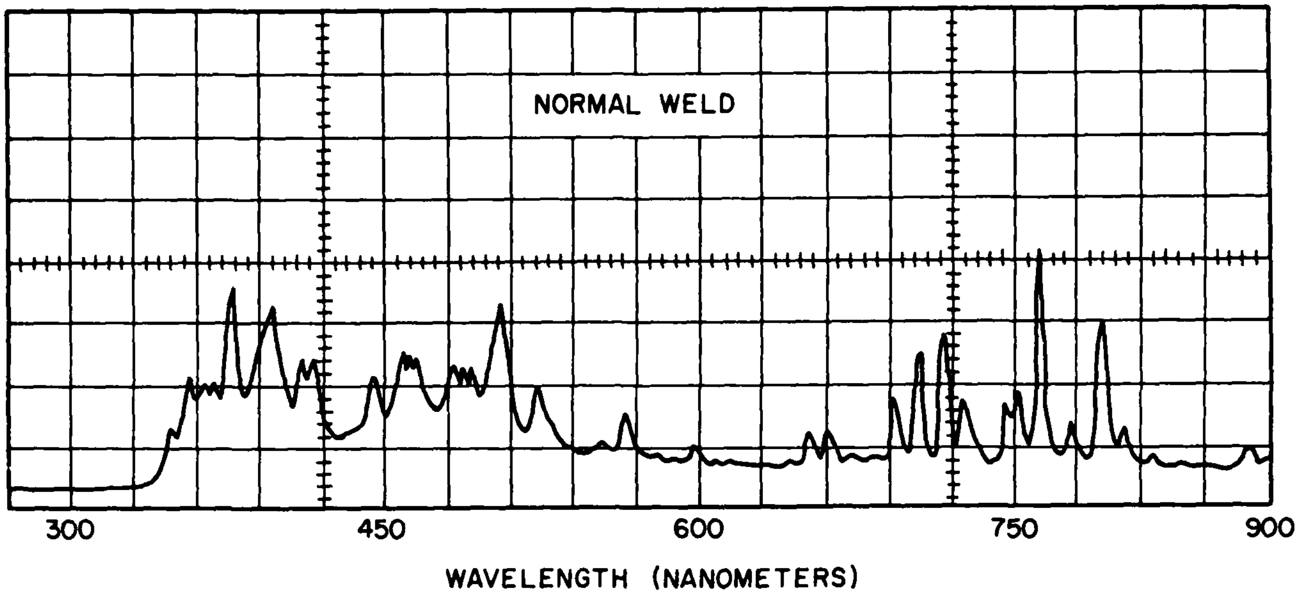
Sharpe, R. W., *Research Techniques in Nondestructive Testing* (Academic Press, 1970).

Simon, R. E., *Electro-Optics Handbook* (RCA, 1974).

Weber, R. A., and C. E. Jackson, *Review of Weldability of Construction Materials*, Interim Report M-183 ADA027383 (CERL, January 1976).

Weber, R., F. Kearney, and S. Joshi, *Development of a Weld Quality Monitor*, Interim Report M-183 ADA027644 (CERL, July 1976).

Welding Handbook (American Welding Society, 1976).



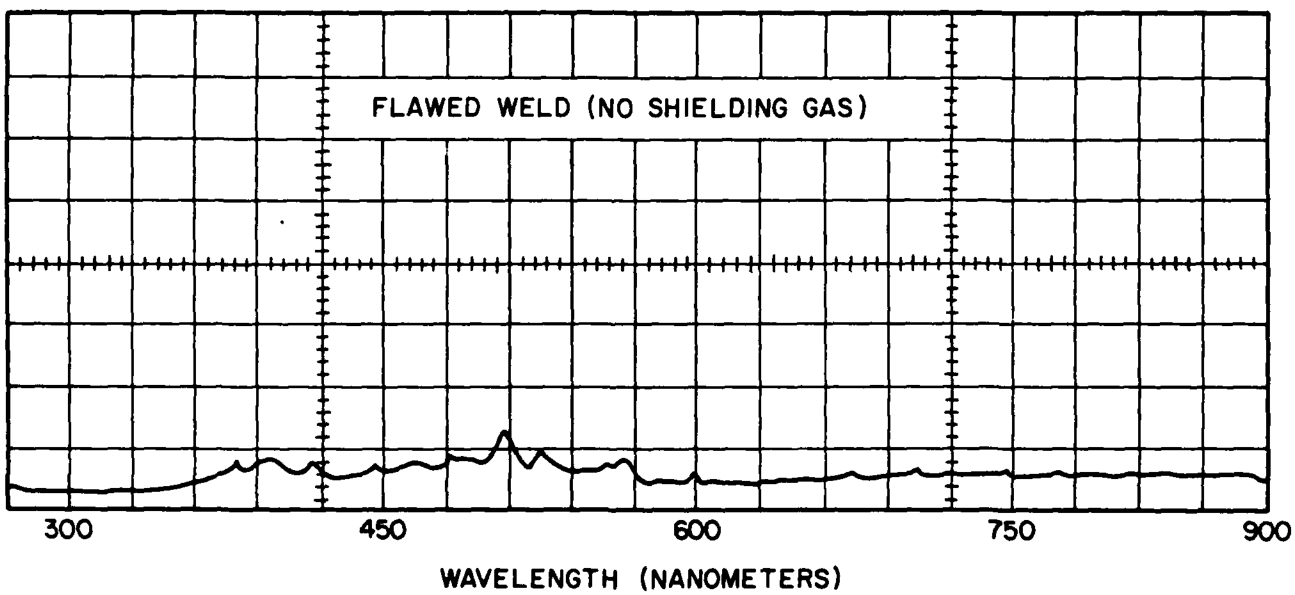


Figure C3. Spectra obtained from CERL weld quality monitor arc spectral analyzer.

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Kearney, Frank W.
Nondestructive testing for field welds : real time weld quality monitor, field tests/by F. Kearney, R. Weber, P. Williams. -- Champaign, IL : Construction Engineering Research Laboratory ; Springfield, VA : available from NTIS, 1981.
16 p. (Technical report ; M-295)

1. Nondestructive testing. 2. Welded joints -- testing. I. Weber, Robert A. II. Williams, Peter. III. Title. IV. Series : U. S. Army. Construction Engineering Research Laboratory. Technical Report ; M-295

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